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Influence of Inoculum - Substrate Ratio on the Anaerobic Digestion of Bagasse Based Paper Mill Effluent in Batch Process

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Abstract : In recent years, anaerobic digestion has proved to be a more versatile in treatment of industrial wastewater. Batch digestion experiments were conducted to determine the effects of Inoculum - Substrate Ratio (ISRs) of five different ratios 0.5, 1.0, 1.5, 2.0 and 3.0 for 168 hours period. The substrate chosen in this study was bagasse based paper mill effluent. The inoculation was made by sludge issued from wastewater treatment plant. During this study, several parameters of anaerobic digestion were measured, such as pH, VFA and TA. The results obtained were demonstrated that the ISRs range from 0.5 to 3.0, the pH ranged from 6.32 to 7.2 and this parameter was always stable during the anaerobic process. In addition, within the above ISRs range the VFA/TA ratios were always lower than the failure limit value 0.5, which depicted the high stability of anaerobic digestion process in batch made. The bio gas productivity was estimated for various batches of inoculum – substrate concentration and biogas productivity was observed more as 55 ml for ISR 0.5.
Keywords : Anaerobic digestion; Inoculum-substrate ratio (ISR); Bagasse based Paper mill effluent; Batch process; Sludge; Process stability.

1. Introduction

The paper industry, as it stands now, is one of the largest industries in India and it is one of the major producers of paper in the world and varieties of papers and similar products are now manufactured in different mills throughout the country. [1, 2]. Large integrated paper mills from private and public sector with a product mix of all varieties of paper (writing, printing, packaging, specialty, paperboards and newsprint) located in all regions and using conventional fibre such as wood and bamboo and also unconventional raw materials like recyclable waste paper, agro-residues, viz. bagasse and wheat straw; approximately 31% are based on wood, 47% on recycled fibre and 22% on agro-residues [3]. The paper mill produces variety of writing and printing paper using bagasse, a sugarcane residue, as a primary raw material. The wastewater generated from the paper mill consists of white water from stock preparation, paper machine and from the bleach section etc. The colour of the effluent was appeared to be light brown to yellowish brown in colour against the standard limit. This may be due to the presence of lignin compound present in the raw material used for paper production.

With rapid depletion of conventional energy sources, the need to find an alternative, preferably renewable, source of energy from waste is becoming increasingly important for the sustainable development [4]. It is important to evaluate appropriate techniques to recover the energy from the waste. Anaerobic digestion processes are a popular technology for the treatment of industrial wastewater, and they are broadly used around the world. The main advantages of anaerobic digesters are their low energy requirement and minimal

production of excess sludge. They can also be combined with the use of other processes to effectively remove organic matter and nutrients [5]. This combination is a promising alternative to the traditional treatment of industrial wastewater.

Anaerobic digestion of pulping wastewater and sludge has been evolving to analyze the potential recovery of energy in the form of biogas. This process presents the effective wastewater treatment that produces biogas and moreover minimizes the volume of the sludge generated by 30% and 70% [6]. Such an approach can reduce additional problems associated with the exponential generation of waste. Anaerobic digestion helps breakdown the biodegradable organic fraction presenting in waste by turning it into biogas with high methane content, thus having a high energy use and a stabilized final effluent. Hence, anaerobic digestion presents a positive energetic balance, allowing both pollution prevention and recovery of sustainable energy [7]. This not only offers potential use of biogas for heat and electricity, but also allows the possibility of upgrading the biogas into bio-methane and using it as vehicle fuel.

Meanwhile, the inoculum to substrate ratio (ISR) has been shown to affect the consumption of volatile fatty acids (VFAs), methane production rate, and methane yield. The ISR is generally presented on the basis of volatile suspended solids (VSS). The ISR affects the duration and occurrence of the lag phase (extracellular hydrolysis), VS/chemical oxygen demand (COD) reduction, methanogenesis, and susceptibility of micro-organisms to inhibitory effects [8]. The ISR is a major parameter that affects the process of anaerobic digestion. Dealing with the long and difficult start-up periods of anaerobic reactors can often be frustrating for researchers in the laboratory. The ISR is a crucial parameter, but it is unfortunately excluded by many researchers from the experimental design [9]. Mean- while, few studies have reported on the start-up variation techniques of anaerobic digestions.

Many studies have reported on the inoculum substrate ratios (ISRs) for different substrate such as pharmaceutical effluent, sunflower oil cake mill, bioethonal plant waste, slaughter house waste, and maize etc. [10, 11, 12, 13, 14]. However, fewer more studies have reported on the methane potential of pulp and paper mill effluent and have concluded on a positive yield of methane ranging from 40% to 60% of the theoretical potential [6, 16]. However, a setback using in anaerobic digestion for pulp and paper mill effluent is the fact that these effluents are highly loaded with different toxic compounds that can inhibit the AD process and also have a high amount of lignin and extractives that have low degradability. Here the attempt has been made with the bagasse based paper mill effluent with different ISRs having the different concentration of substrate and the constant inoculum concentration of municipal sewage sludge to hone the inoculums substrate ratio for the process stability and efficient biogas production.

2. Materials and Methods

2.1 Substrate and inoculums

The substrate that was used asa raw bagasse based paper mill waste and it has been collected from the bagasse based pulp and paper mill located at TNPL Kagithapuram, Karur. The grab samples were collected in the plastic containers and brought to the environmental laboratory in Department of Civil engineering, Annamalai University and which were refrigerated at 4° C prior to further analysis in the laboratory. The characteristics of the substrate were studied and analyzed [17].

The analytical methods for the analysis of the samples were determined by the standard procedures given in APHA of waterandwastewater21thedition2005. Based on literature study [13] the substrate were prepared and used for the present study. This prepared substrate material was expressed in terms of volatile suspended solids (VSS/l) which contains the composition of CHONS (in percentages) of the waste [11]. The inoculums of municipal sewage sludge collected from sewage treatment plant, Kumbakonam. The inoculum was having high methenogenic activity. The substrate was having the volatile suspended solids (VSS) concentration and the total solids (TS) concentration of 19.26% and 86.72% respectively. The inoculum characteristics were expressed in terms of volatile solids (VS) and total solids (TS) of 16.27% and 58.32% respectively.

2.2 Experimental setup

The experimental study was carried out in a batch reactor system, which consisted of 5 serum bottles, with an effective volume of 1000 ml. For each ISRs assayed the operational batch reactor system were initially charged with the corresponding amount of substrate and one of them was sacrificed and removed every day to study the evolution of the chemical parameters at various times in the anaerobic digestion process. The duration of the experiments was 168 hours in all cases. This short period of time was long enough to achieve the maximum biogas production and can basically be explained by the high methanogenic activity of the sludge [11].

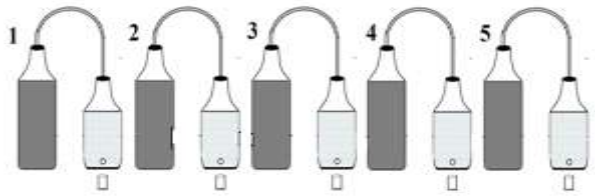

Fig. 2.1 Experimental set up of anaerobic batch process

2.3 Anaerobic Batch Process

The experiments were carried out in batch mode operation for the anaerobicbiode gradability of bagasse based paper mill effluent. The tests were carried out in five batch reactors of same volume. Serum bottles of 1000 ml with rubber caps of appropriate size. Five different inoculum substrate ratios (ISRs) such as 0.5, 1.0, 1.5, 2.0 and 3.0 were achieved by keeping constant inoculums concentration and varying the substrate concentration. Each set of batch reactorwasfilled with an inoculum of municipal sewage sludge. The bottles were closed tightly so thattheanaerobic condition ismaintained. The bottles were incubated at ambient temperature (32°C-35°C) of mesophilic range. Thebiodegradability wasmeasured byusingvariousparameters suchaspH, total alkalinity and volatilefattyacidasper the standardmethods for theexamination of water and wastewater, (APHA, 2005). The biodegradability of batch process was measured in a single phase of 168 hours. This measurement was donetoobserve the rapid influence ofinoculum on anaerobic biodegradation. The bottles were carefully stirred beforegasmeasurement. The substrates were added to a mixture of inoculum along with carbon, nitrogen and phosphate nutrients. The biogas produced wasmeasured volumetrically bywater displacement method. All the experiments were carried out in triplicate and the results were expressed as means. The experiments were conducted until a small production of biogas was observed.

3. Results and Discussion

The experiment results of batch system for various inoculum substrate ratios (ISRs) 0.5, 1.0, 1.5, 2.0 and 3.0 on the inoculums of sewage sludge acclimatized with substrate are presented and discussed in this chapter. These results are explained to highlight the significance of salient details obtained from the experimental study. It is required here to explain the effect of degradation of bagasse based paper mill effluent that leads to management and treatment of high strength waste. A comprehensive experimental study, with appropriate inoculum ratio for the substrate was carried out using municipal sewage sludge. There results could be explained; the best ratio of inoculum substrate had stable anaerobic degradation withthebagasse based paper mill effluent.

3.1 Process stability

pH is a very interesting indicator in the stabilization process it shows us the good behaviour of the anaerobic digestion. Anaerobic processes are strongly influenced by changes in pH. As can be seen in Fig. 4.1 the pH ranged from 6.32 to 7.03, the lowest value corresponding to the ISR of 0.5 at 24 h of digestion time. In all the ISRs initially the pH was decreased and it was increased from 48h to 96h and finally stabilized from 120h to 168h. This increase was due to the fatty acids were consumed by the acetogenesis bacteria. These pH values were compatible with the normal growth of anaerobic microorganisms. Furthermore no imbalance was observed in the pH even when the ISR used was at 0.5. This shows that this parameter was always stable during

the anaerobic process. With ISR 0.5 the highest concentration of VFA was produced which brought on an almost complete stop of methane production.

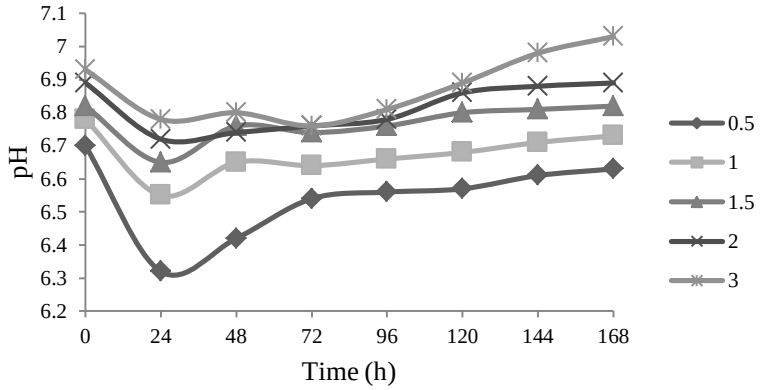

Fig.4.1 Variation of pH of digestates for different ISRs

Several observations related to anaerobic digestion suggest that volatile fatty acids (VFA), as one of the most important parameters for the accurate control of anaerobic digestion, have a direct correlation with the digester performance. During the anaerobic acid phase stage of complex organic substrates, mainly constituted by carbohydrates, proteins and lipids are converted basically to volatile fatty acids (VFA) and to a lesser amount of other low molecular compounds [11]. The values of VFA were proportional to the amount of substrate added, and no accumulation at the end of the digestion time happened at 3.0, 2.0, 1.5 and 1.0. However, for ISRs lower than 1.0, an imbalance of the process was observed that the VFA concentration was increased up to 4390 mg acetic acid/l for ISR of 1.0 as was previously reported in the finding [11]. After this the ISRs of 1.0 and above the VFA values increase to 2234 mg of acetic acid/l. This increase and decrease of VFA was observed which is due to VFA consumption by bacteria corresponds to acitogenesis phase results in the stability of anaerobic digestion [14]. The reactional medium has a high rate of alkalinity that allowing it to ensure a good anaerobic digestion operation. For ISR of 0.5 characterized by an increase in the TA values around 6800 mg/l from findings. This was apparently showed that this TA values were destabilize the anaerobic digestion. Furthermore, no imbalances in the TA values of the ISRs ratio of 1.0, 1.5, 2.0 and 3.0.

The VFA/TA ratio can be used as a measure of process stability [18] when this ratio is lower than 0.5 (equiv. acetic acid/equiv. $CaCO_3$) the process is considered to be operating favourably without the risk of acidification. Fig. 4.2 illustrates the VFA /TA ratio values, and shows that the ratio was during the whole experience period less than 0.5 rather than the ISR value 0.5. For this VFA/TA ratio was around 0.7 during all digestion times which clearly showed the destabilization of this digester. Furthermore, there were no imbalance was measured during the digestion of ISRs 1.0, 1.5, 2.0 and 3.0. This indicates the feasibility of the process even with the significant production of VFA whose presence may inhibit the anaerobic digestion process. Several authors consider that the control of VFA, pH and TA is necessary for a good operation of the anaerobic digestion.

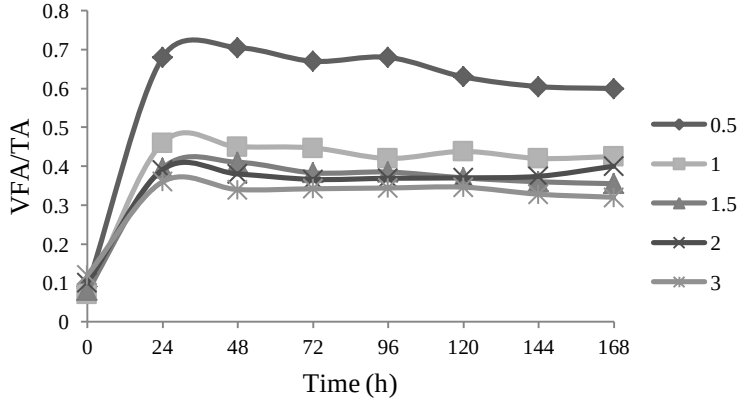

Fig.4.2 Variation of VFA/TA Ratio with digestion time for different ISRs

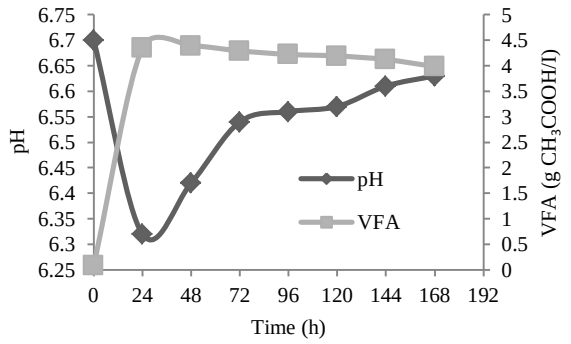

Fig. 4.3 (a)

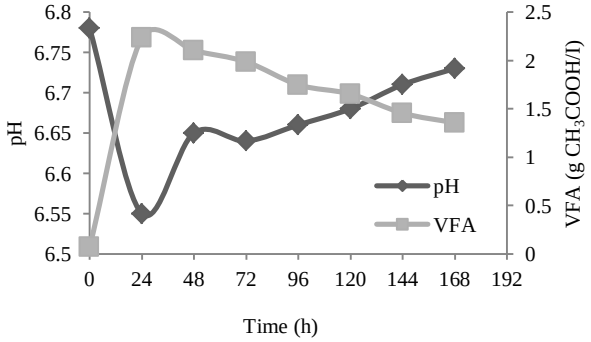

Fig. 4.3 (b)

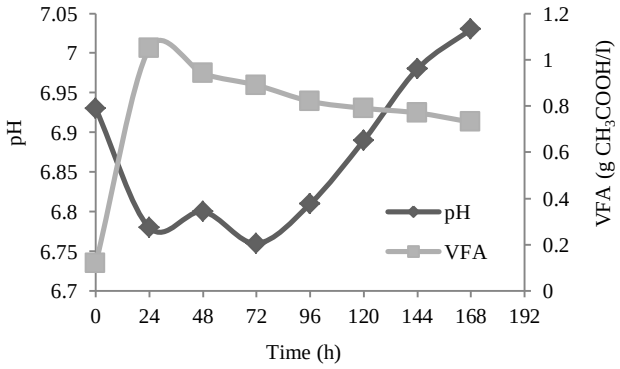

Fig. 4.3 (e)

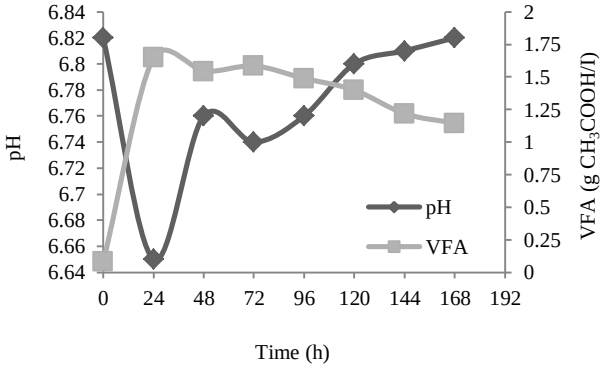

Fig. 4.3 (c)

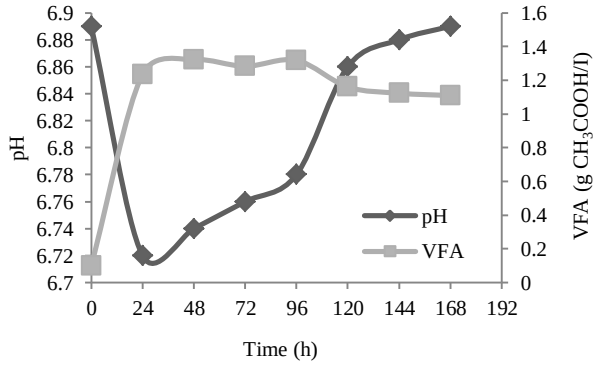

Fig. 4.3 (d)

Fig. 4.3 pH and VFA Variation (a) 0.5 ISR (b) 1.0 ISR (c) 1.5 ISR (d) 2.0 ISR (e) 3.0 ISR

Fig. 4.3 illustrates the relationship that may exist between the VFA and pH during anaerobic digestion. It was noted that the reverse in case compared another form. So the variation of the two parameters is inversely proportional in the entire ISRs ratio chosen for this study. Several authors consider that the control of VFA, pH, and TA is necessary for good operation of the anaerobic digestion.

3.2 Biogas production

The experiments lasted for 168 hours. Fig. 4.4 shows the cumulative biogas production of paper mill effluent as a function of time at different (ISRs) ratios. As can be seen, the biogas production increased as the

(ISRs) value decreased. The cumulative biogas production from 0 to 168 hours of digestion for different ISRs 3.0, 2.0, 1.5, 1.0 and 0.5 was 37ml, 42ml, 47ml, 51ml and 55ml respectively. The substrates amount contributed substantially in increasing the amount of produced biogas [10, 15].

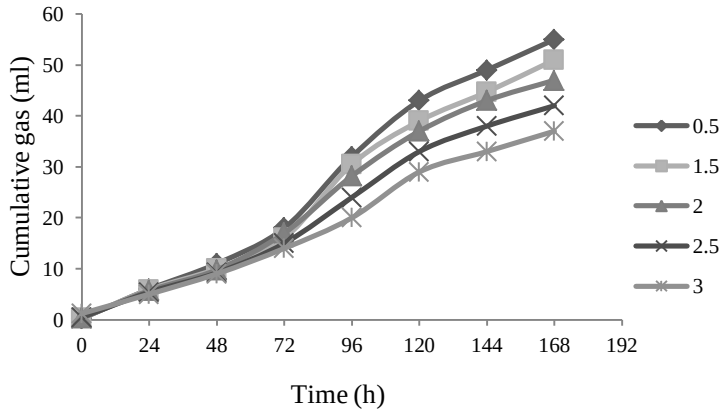

Fig. 4.4: Cumulative biogas production during anaerobic batch digestion at different ISRs

4. Conclusion

The stability and progress of the reaction from bagasse based paper mill substrate to biogas as an end product was monitored by measuring the pH, volatile fatty acids-total alkalinity and (VFA/TA) ratio. The results obtained demonstrated that in the inoculum-substrate ratios (ISRs)range, the pH ranged from 6.5 to 7 and this parameter was always stable during the anaerobic digestion process. In addition, within the above (ISRs) range the VFA/TA ratios were always lower than the failure limit values of 0.5 rather than the ISR 0.5, which demonstrated the high stability of the anaerobic digestion process of this substrate. The Cumulative biogas production increased as the (ISRs) value decreased. The production of VFA has not inhibited the anaerobic digestion process; this is due to the buffering capacity of the medium. It was observed that the lower ISRs 0.5, which demonstrates a clear imbalance of the process and ISRs more than 1.0 which states more stable in the anaerobic digestion.

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